Crooker

Influence of a Series Spark on the Direct Current Corona

INFLUENCE OF A SERIES SPARK ON THE DIRECT CURRENT CORONA

BY

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I HEREBY RECOMMEND THAT THE THESIS PREPARED UNDER MY SUPERVISION BY Sylvan Jay Crooker.

ENTITLED Influence of a Series Spark on the Direct Current Corona.

BE ACCEPTED AS FULFILLING THIS PART OF THE REQUIREMENTS FOR THE DEGREE OF Doctor of Philosophy in Physics.

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Sylvan J. Crooker.

I

INTRODUCTION

1- Statement of the Problem.

In the paper, "Corona Produced by Continuous Potentials" (A.I.E.E. 1914 p.1721.) Stanley P. Farwell described some experiments in which he noted changes in the appearance of the direct-current corona discharge between coaxial cylindrical electrodes when a short 'arc', as he calls it, was placed in series with the corona tube. He says that " the typical quiet bluish positive discharge is more brilliant, of a purple tinge and greater in diameter. The typical discontinuous negative discharge has its character changed most markedly by the introduction of the arc", and he attempts to explain this by assuming that the 'arc' sets up high frequency oscillations superimposed upon the direct-current phenomenon.

These changes in the corona discharge seemed to be of sufficient interest to justify a more extended study and if possible measure the oscillations and form an explanation for them.

Farwell should have used the term short 'spark' since this is in reality what he had. Perhaps he did not recognize the distinction between the spark and the arc taking place across a short air gap but subsequent experiments have shown that the discharge is in every case a spark when corona is seen on the wire. However the current passing in the corona tube may become large enough that the discharge between the cylinder and the axial wire takes the form of the arc. Only in this case is it possible to have an arc between the electrodes of the

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series air gap and of course the discharge in the corona tube is no longer a corona.

The spark and the arc may be distinguished in several ways. The former is an intermittent phenomenon each spark lasting but a small fraction of a second whereas the latter is a continuous one lasting as long as energy is supplied. The spark usually takes the form of a narrow white line in the gas between the electrodes while the arc is of comparatively large diameter and of different color depending on the nature of the gas and of the electrodes.

The first questions which arose from Farwell's hypothesis were those relating to a critical qualitative study of the action on the corona discharge of a short spark in series with the electrodes of the corona apparatus, as well as the detection and measurement of the assumed oscillations.

A series of qualitative experiments were performed in which the visual characteristics of the positive and negative corona were studied when a short spark was placed in series with the wire or the tube. The appearance of both the positive and negative corona glow was changed by the introduction of a spark. The usual characteristic negative beads spread out laterally and in diameter into a fuzzy glow (blue in air), whereas the quiet uniform positive glow gives place to a remarkable display of purple 'streamers' shooting out radially from the wire to the tube and at times completely filling the tube with light. These visual characteristics (the broken negative beads and the positive streamers) were found to be essentially the same in all gases.

A repetition of Farwell's experiments along with several other different experiments disprove the existence of oscillations in the

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corona. Additional experiments help us to understand the real nature of the glow discharge.

2. Apparatus.

The high potential was supplied by a battery of forty 500 volt, 0.5 ampere, self-excited, direct-current generators connected in series. The generators were driven in two sets of ten and one of twenty by direct-current motors that received their power from a constant-voltage machine. A very steady potential was available up to 20,000 volts. Individual generators could be cut in or out by closing or opening the field switches giving a voltage variation in steps of 500 volts. Smaller variations in voltage could be made by the adjustment of a rheostat which was connected in series with the field of one of the generators.

The corona discharge took place between coaxial cylindrical electrodes the outer one being a brass cylinder 3.6 cm. inside diameter, 25.4 cm. long with a 1 cm. longitudinal slot for observation, and the inner one being a small copper wire (No.20 to No.28 B and S). These were sealed into a glass tube which was connected to a vacuum pump and a manometer. This tube is shown in Fig.1.

The electrical connections of the corona tube with the auxillary apparatus is shown in Fig.2.

The electrodes of the spark gap were polished brass spheres 1cm. in diameter fastened to brass rods which were supported by hard rubber blocks on a solid hard rubber base. One of the electrodes was supplied with a micrometer screw and an insulated handle which permitted an easy adjustment of the spark distance. This spark gap was connected in series with the self-opening line switch and the corona

Fig. 1

The Corona Tube

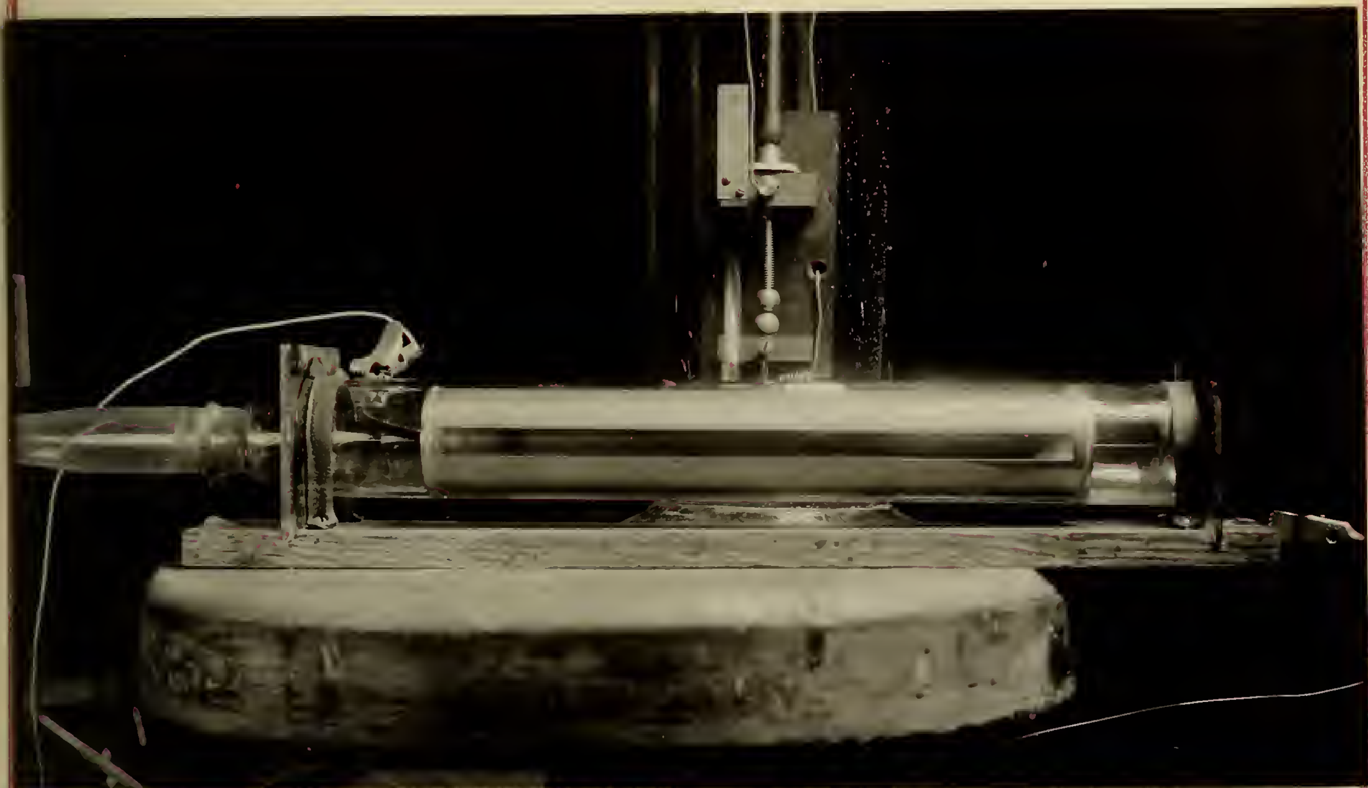
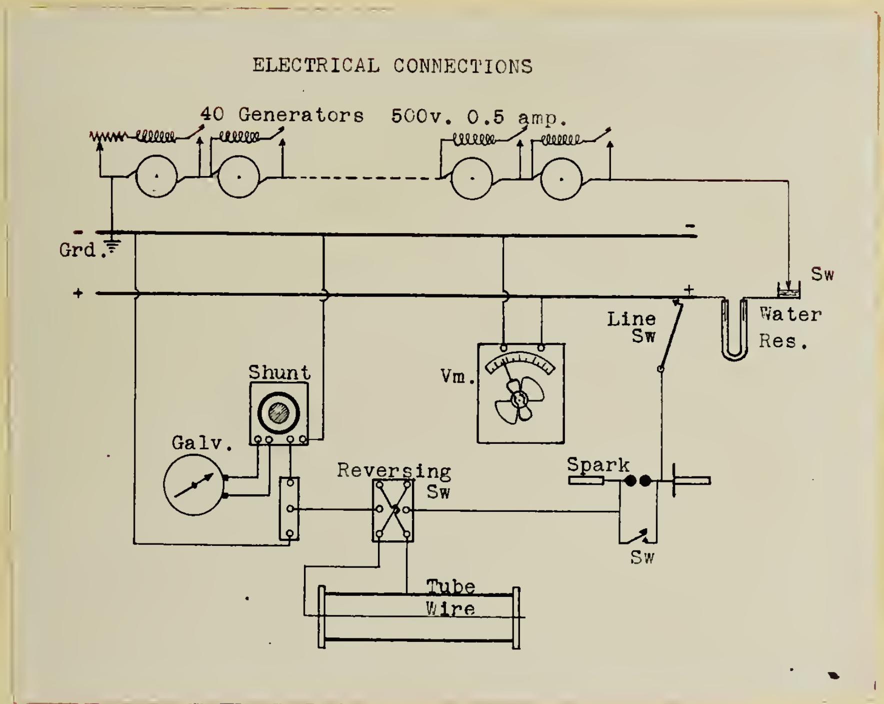


Fig. 2

Electrical Connections



tube thru a reversing switch which allowed quick reversal of the polarity of the axial wire.

A D'Arsonval galvanometer (944ω) with an Ayrton universal shunt (3000 ω) was connected to the tube on the grounded side of the line. The current per centimeter scale deflection at a distance of 1 meter was found to be $I = n\ 1.775 \cdot 10^{-7}$ amperes, where $n = 1, 10, \ldots$ depending on the setting of the shunt.

A Kelvin electrostatic voltmeter (0 to 20,000 volts) was used for the potential measurements. This was calibrated by means of an attracted-disc electrometer of the Kelvin absolute type. The formula and constants for the electrometer are given as follows:--

$$\text{Absolute volts, } V = D\sqrt{8\ \pi\ g\ W/A} = D\sqrt{8\ \pi\ g\ W/\pi B}$$

$$= D\sqrt{8 \cdot 980.2/B}\ \sqrt{W} = C\ D\ \sqrt{W}.$$

D = distance between the plates.

W = weight in grams to balance.

R = radius of disc = 3.5016 cm.

R' = radius of aperture = 3.5525 cm.

$\alpha = 0.220635\ (R' - R) = 0.0112193.$

$$B = 1/2\ (R^2 + R'^2 - (R'^2 - R^2)\ \alpha/(D + \alpha)),$$

$$= 12.44096 - .0002516/(D + .01122),$$

$$= 12.44096 \text{ approximately.}$$

$$V = D\sqrt{W}\sqrt{8 \cdot 980.2/12.44096}$$

$$= 25.105\ D\sqrt{W}.$$

$$\text{Practical volts, } V = 7531.5\ D\sqrt{W}.$$

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3- Preliminary Experiments.

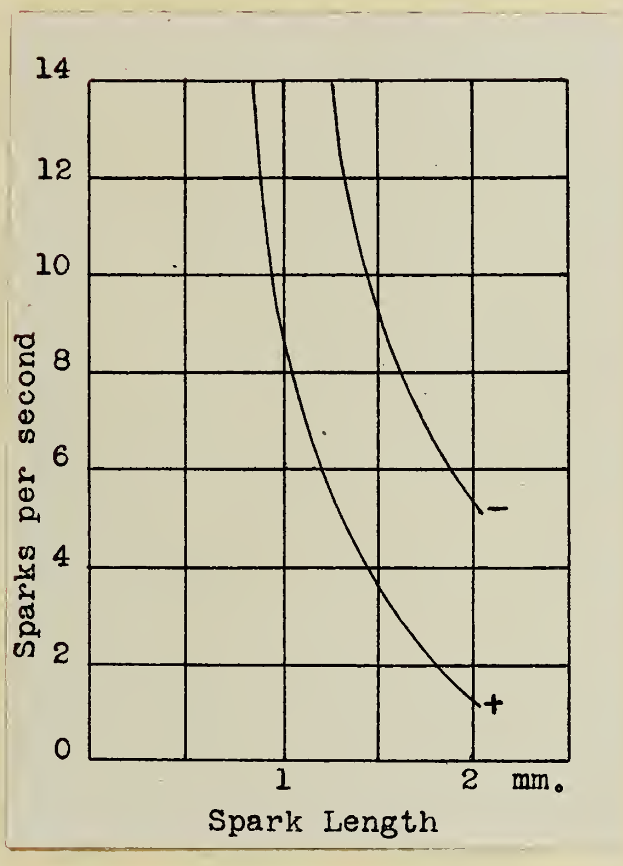
In the preliminary experiments a telephone receiver connected in parallel with a resistance was used in place of the galvanometer in attempting to detect the assumed oscillations. This arrangement was very effective since the passage of the faintest spark could be detected. When the voltage was high enough to produce corona as each consecutive spark passed a sharp click was heard in the telephone and a flash of glow appeared on the wire in the tube. If the sparks passed in very rapid succession the glow would appear to be practically continuous.

The corona tube acted like a condenser charging up and discharging at intervals depending on the length of the spark gap. It could be arranged so that, for long sparks, only one spark would pass per second, or for short sparks, several thousand passed per second, and as each spark passed it would register a sharp click in the telephone receiver. On decreasing the spark length from the longest sparking distance the sparks would jump faster and faster until for very short spark lengths the sound in the telephone passed practically out of the audible range.

For a given spark length more sparks would pass per second if the axial wire was charged negatively than when it was charged positively. This is to be expected since the current passes thru the tube easier when the wire is negative. For a given constant line voltage and air at atmospheric pressure, plotting the spark length against the frequency of the passing sparks for both positive and negative wires, curves as shown in Fig.3 are obtained.

Fig. 3

Spark length-Frequency Curves



4- Characteristic Direct Current Corona Glow.

(a) in Air.

A detailed description of the appearance of both the positive and negative corona has been given by the writer (Phys.Rev. V.8 No.4 p.344 Oct.1916) for various surface conditions of the wire and for various pressures of the gas in the tube. The positive glow in air encases the wire in a uniform bluish layer of small thickness which increases in brightness as the voltage is increased, see Fig.4. This glow is in general of the same character for all voltages, pressures and wire surfaces. The negative corona in air may take different forms depending on the voltage, pressure and surface condition of the wire. In general however the starting negative glow is of a uniform distribution along and around the wire of about the same color but of larger diameter than that for the positive wire. This starting glow is rather unstable and may easily break up into the characteristic negative beads or condensed regions of glow which space themselves along the wire at approximately equal intervals. At low pressures these beads are large and few in number, but increase in number and brightness as the voltage is increased. Irregularities on the surface of the wire may split the beads up into small sharp spears of light or into irregular fuzzy glow. The clear evenly spaced beads are the most characteristic form of the negative glow discharge.

(b) in Illuminating Gas.

While the general visual characteristics are the same in both air and illuminating gas still there are slight differences which might be mentioned. The negative beads are formed much clearer and are steadier than in air. The beads have an intense bright greenish color and at times a flash of white light is seen on the wire at the

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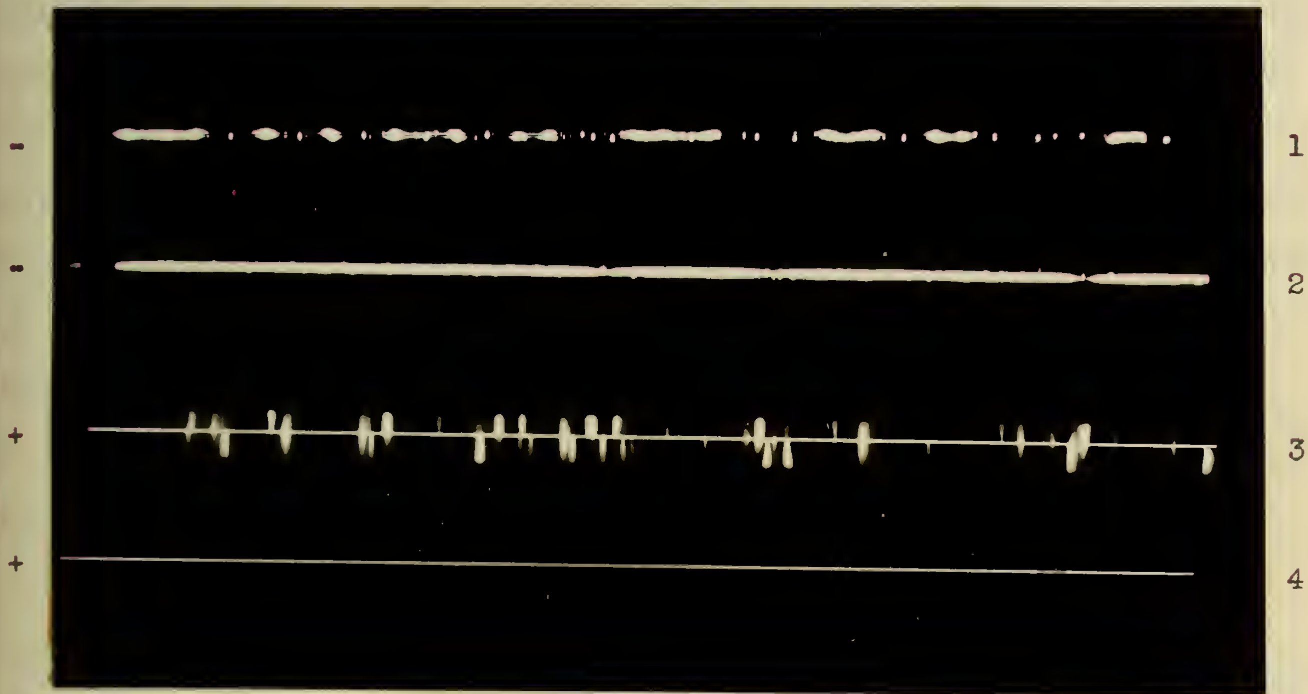
Fig. 4

Corona Discharges with and without a series spark



1 and 4 without spark.

2 and 3 with spark.

core of a bead as tho some of the metal became incandescent for an instant. The positive glow is also of a blue-greenish color but it was difficult to get the characteristic uniform positive glow except at low pressures. At the higher pressures we seemed to get real positive beads or regions of condensed glow of large diameter similar to the negative beads and interspersed with regions of more hazy glow. These beads were quite steady but much larger and less bright than the negative beads. These were at first thought to be due to a bad connection causing a short series spark but after going over all contacts and repeating the experiments even with another tube the same results were obtained. Moreover these regions of condensed positive glow are different from the positive streamers in that they are more symmetrical, practically encompass the wire and are less bright. Here is an exception to the usual form of the corona glow on a positive wire.

Note. This illuminating gas is an enriched water gas composed essentially of CO and H.

(c) in Hydrogen.

It is found that the starting corona voltages are very much less in hydrogen than in air. The positive and negative characteristic appearance of the glow is much the same as for air with exception to the color which is generally of a milky blue-white tinge. The positive glow is uniform the same as for air and the negative beads while brighter and of different color have the same characteristic shape. It is very easy for the negative beads to go over into an arc. This is shown in a later section, 'Corona and the Arc'.

5- Characteristic Corona Glow with Spark in series.

(a) Positive.

If a short spark is placed in series with the corona tube, containing air at atmospheric pressure, after the voltage is high enough to give a bright uniform glow a most remarkable change takes place in the discharge. For very short sparks a few bright purple radial pencils or streamers of light will shoot out irregularly from the wire toward the tube. These streamers increase in number and in brightness as the spark gap is opened and may at times completely fill the tube with purple light. They are brighter and more easily formed at the higher pressures and at voltages slightly above that for the starting glow, but they have been observed at pressures as low as 30 mm.

The same changes in the appearance of the positive glow by the introduction of a series spark have been observed in illuminating gas and hydrogen. The uniform positive glow is in both cases transformed into the radial streamers by the action of the spark. In illuminating gas these streamers are of an intense blue-green color while in hydrogen they are of a milky white or silvery appearance.

(b) Negative.

A short series spark has the effect of destroying the characteristic negative beads. On introducing a very short spark the clear beads are reduced in brightness and lose their clear cut form becoming hazy at the boundaries. Gradually opening the spark gap causes a slow transition of the beads from the clear intensely concentrated form of glow to a uniform fuzzy glow which spreads out laterally from the beads along the wire and which is slightly larger in diameter than the original beads. The bright cores of the beads maintain their positions

until the last altho they are greatly reduced in intensity, and may even be seen when the spark gap is so long that the glow flashes but intermittently.

The characteristic destruction of the clear form of the beads due to the action of the spark has also been observed in illuminating gas and in hydrogen at various pressures.

It made no difference whether the spark gap was placed on the grounded side of the tube or on the high-potential side, the appearance of the glow remained the same. If the electrodes of the tube were short-circuited an arc would form between the electrodes of the spark gap immediately upon the passage of the first spark.

II

OSCILLATIONS IN THE CORONA

1- Farwell's Evidence for Oscillations.

At times when the spark is placed in series with the corona a marked hissing sound is heard due to the rapidly passing sparks and to the adiabatic expansion of the ionized gas. Farwell attributed this to oscillations set up in his 'arc'. He also states that the appearance of the corona is of the ordinary forms for both positive and negative when a 2 m.f. condenser is paralled with the tube and wire, and that the appearance is not changed by the introduction of a spark in series. The condenser is said to be slow in charging and discharging and the current from it is shown by rough calculation to be unidirectional.

This is the only evidence given in support of the presence of oscillations, but at first sight both the positive and negative corona glow, as produced with a spark in series, might appear to be of the same general character. That is, the uniform positive glow is changed to a fuzzy looking glow of larger diameter and the negative beads are also changed into a fuzzy glow. This might seem to show the presence of oscillations but upon closer examination a marked difference is seen in the appearance of the positive and negative glow discharge.

If oscillations were present the condenser might take up the high frequency impulses and by rough calculation it might discharge a unidirectional current, but with a high frequency alternating current impressed the condenser would not charge up slowly to a high potential with charges of one kind on one plate and those of the opposite kind on the other. However if we had unidirectional impulses in the spark the condenser would act to cushion them and not allow

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them to pass thru the tube, but would on the other hand build up gradually to a high potential and discharge a unidirectional current thru the tube.

2- Repetition of Farwell's Experiments.

A condenser of about 0.03 m.f. capacity was connected in parallel with the corona tube and wire. The visual appearance of the discharge being studied at different pressures with and without a spark in series. It was experimentally observed that the charging spark of the condenser was a rapid series of unidirectional sparks and the discharging spark was but a single fat spark also unidirectional.

As a spark passes the telephone connected in series with the tube emits an altogether different sound when the condenser is introduced. Without the condenser in parallel as each spark passes a very sharp 'click' is heard in the telephone but when the condenser in connected the sound is like a thump or 'punk'. As the spark gap is shortened these thumps come more frequently but still sound the same until the gap is completely closed when a very clear singing noise is heard. This is different for the circuit without the condenser when gradually closing the gap the sharp clicks melt into a high pitched hissing sound which seems to go beyond the audible limit just before the gap is closed. When the electrodes touch there is no appreciable sound heard in the telephone and apparently the current passing is continuous.

Several series of experiments were performed in both air and in illuminating gas at pressures of about 50 mm., 250 mm., and 740 mm., with and without spark and condenser. Barring slight differences the essential characteristics of the glow were the same in both gases and and at the different pressures. To show the general effects produced

produced by the spark and the condensers, alone as well as in combination, upon the corona discharges one set of experiments will be recorded in detail.

AIR. At a pressure of 253 mm. a potential of 6,000 volts produced a good corona glow on the No.22 copper wire which was strung in the tube.

WITHOUT CONDENSER

Wire -. No spark.

A few clear beads interspersed with a small ammount of fuzzy glow are formed on the wire. The beads are somewhat unstable forming and breaking up again from time to time.

Wire -. 0.14 mm. Spark in Series.

The clear beads are replaced by a fuzzy blue-purple glow which becomes brighter and of slightly larger diameter. Only faint remnants of the bead cores are left here and there on the wire.

Wire +. No Spark.

A steady uniform bluish glow encases the wire.

Wire +. 0.14 mm. Spark in Series.

Intensely bright purple streamers shoot out radially from the wire to the tube dancing along and about the wire rapidly.

WITH CONDENSER

Wire -. No spark.

A few clear beads and fuzzy glow. The same as before.

Wire -. 0.14 mm. Spark in Series.

The glow is not much different from that without the spark except that it is less bright. The condenser seems to stabalize the glow and cushion the impulses from the spark. Upon opening the line switch the glow slowly decays as the condenser discharges.

Without the condenser the glow disappears immediately upon opening the switch.

Wire +. No spark.

A steady uniform bright bluish glow the same as above.

Wire +. 0.14 mm. Spark in Series.

The glow is fainter but uniform. It is impossible to get the radial purple streamers in any case with the condenser in parallel. Upon opening the switch the glow decays slowly from the ends of of the wire toward the center. For long sparks the glow is weakened more and flashes with the spark but maintains its uniformity thruout.

The general results produced by the spark and condenser upon the visual corona discharge may be summed up as in the following

TABLE I

	WITHOUT CONDENSER	WITH CONDENSER
Wire -.	Negative beads.	Negative beads.
Wire -. With spark.	Fuzzy glow.	Negative beads weakened.
Wire +.	Uniform glow.	Uniform glow.
Wire +. With spark.	Radial streamers.	Uniform glow weakened.

Condenser in Series.

The 0.03 m.f. condenser was connected in series with the tube and the grounded side of the line to see if any peculiar effects would be produced. The ordinary forms of the discharge on both the positive and negative wires with and without a series spark are observed with this arrangement. However the glow is very weak being brightest only when the switch is closed. After that the glow fades away and disappears as the condenser discharges and the ions of the gas in the tube give up their charges.

3- Evidence Against Oscillations.

(a) Visual and Auditory.

Farwell points to the Poulsen arc as an example of a source of oscillations and assumes that the oscillations in his 'arc' and corona tube are set up in a similar manner. However it has been observed that this discharge is not an arc but a spark or series of sparks and hence his analogy cannot hold. On the other hand it is possible to show experimentally as well as theoretically that a spark discharge may be of an oscillatory character when a certain combination of resistance, inductance and capacity are in the circuit. In our experimental circuit we would not expect to find the sparks of an oscillatory character since the resistance is very large and the capacity small which would give imaginary values to the equation for the frequency, $n = 1/2\pi \cdot \sqrt{1/LC - R^2/4L^2}$. The usual conditions for oscillations are a small resistance, a large capacity and a relatively large inductance.

The conditions in the Poulsen arc and the corona tube are quite different so again we cannot make the analogy hold. In the Poulsen arc at a comparatively low voltage (250 volts) a large current passes between the copper and carbon electrodes in an easily ionized gas such as hydrogen. The arc is blown about on the broad ends of the electrodes by means of a magnetic field excited from the same current that passes thru the arc. As the arc moves about it varies the current in the circuit and this in turn sets up oscillations in the secondary of a transformer.

In the corona tube we have at a high potential very small currents passing in an ionized gas. These currents may vary slightly with the passage of the spark but they are in no sense of the word of an oscillatory character. In fact it has been impossible to detect

the slightest trace of oscillations set up in either the spark or the corona tube under the ordinary conditions of experimentation.

The hissing sound which was observed and attributed to oscillations has been shown to be due essentially to the passage of sparks in rapid succession. In view of Mr. Warner's work (Phys.Rev. N.S. V.8 No.3 Sept. 1916) on the sudden increase in pressure due to ionization when the corona starts we may attribute a portion of this hissing to rapid adiabatic expansions and contractions of the gas in the tube.

The marked difference seen in the appearance of the positive and negative discharge with a spark in series also leads us to believe that no oscillations are set up in the tube. The purple radial positive streamers are produced by the spark impulses and the characteristic negative beads are broken up into a fairly uniform fuzzy glow. If high frequency oscillations were present we would expect essentially the same appearance in the discharge whether the wire was positive or negative, but since the difference is apparent we are again led to the conclusion that there are no oscillations.

It has been shown that the telephone records a sharp 'click' each time an instantaneous unidirectional spark passes and a 'punk' whenever an oscillatory spark is discharged. Under the usual conditions the individual sparks produce only a click in the telephone, which again points against oscillations.

Alternating Current and Stroboscope.

A small transformer operating on a 60 cycle 110 volt circuit giving a secondary voltage of about 10,000 volts was connected to the corona tube, the inner cylinder being a No.26 copper wire. A good corona glow was produced at a pressure of 358 mm. in air. The appearance of the glow was similar to the ordinary alternating

current corona, being composed of a fuzzy glow interspersed with more or less distinct beads, and was of the pale blue-purple color characteristic to air.

By placing a spark in series with the tube it was possible to get the characteristic purple streamers as appear on the positive wire with direct-current and spark. The streamers were few in number for a short spark but increased to a maximum number and decreased again as the gap was opened. The fuzzy glow could be maintained even when the gap was opened beyond the point where sparks ceased to pass. At one time the terminal was taken completely off the tube leaving the wire connected to the transformer and still a faint glow was maintained on the wire.

Viewing the streamers with a stroboscope it was observed that they occurred only at the half cycle when the wire was positive. When the stroboscope was rotated 180° so that the wire was observed only when it was negative no streamers could be seen, only the fuzzy glow and the negative beads were then visible.

(b) Delineation of Currents.

Several methods were tried in attempting to delineate the form of the current which passed thru the spark and the tube. An oscillograph was tried but the currents were so small, being of the order of 10^{-5} amperes, that it proved inadequate since the most sensitive adjustment of the vibrator gave but about one millimeter deflection for a current of one milliampere. A vibration galvanometer was also tried without success, the inertia of the moving mirror was so large that the sudden impulses from the spark could not be followed.

(1) Boys' Method.

The easiest and the most direct method found for studying the current in the spark was that of photographing the spark directly as the image from it swept across a photographic plate. The method is due to C.V. Boys (Phil.Mag. V.30 p.253 and Proc.Phys. Soc.Lond. V.9 p.1 1890) who used a system of six revolving lenses set in one solid disc. Each lens was mounted a little offset from the center of the disc as compared to the adjacent ones so that the image from it would not overlap the others. The arrangement of the apparatus is shown in the Fig. 5. All of the lenses have the same focal length so the spark gap can be focused on the plate thru any one of them. The spark gap and the photographic plate are stationary but since the lenses move the focus of the spark shifts from one point to another across the plate leaving its record of instantaneous images.

A small motor with a speed of 1800 r.p.m. and a pulley 2.5 inches in diameter drives the lenses over a 0.75 inch pulley. This gives the lenses a speed of about 6,000 r.p.m. The lenses are set about 4 inches from the center of the disc so that it is possible to get a linear speed of approximately 100 feet per second across the face of the photographic plate.

By this method it is possible to analyze the spark and easily determine whether it is of an oscillatory or unidirectional character. An oscillatory spark will give an irregular band of light across the plate, see Fig. 6a, while a unidirectional spark leaves only a sharp line, see lines in Fig. 6b.

For rough determinations it is easy to observe the image of the spark on the ground glass plate of the camera and quickly find if the spark is oscillatory or not. If it is oscillatory one can observe

Fig. 5

Arrangement for Photographing the Spark

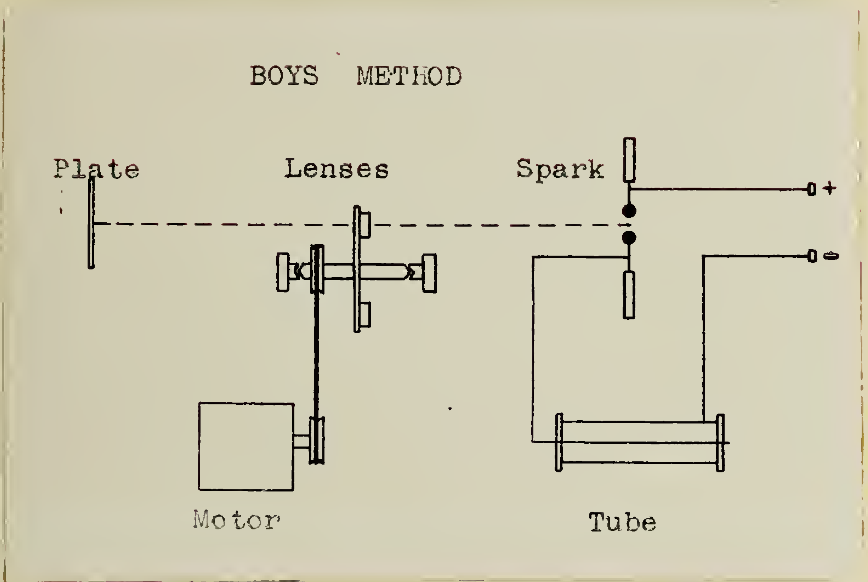
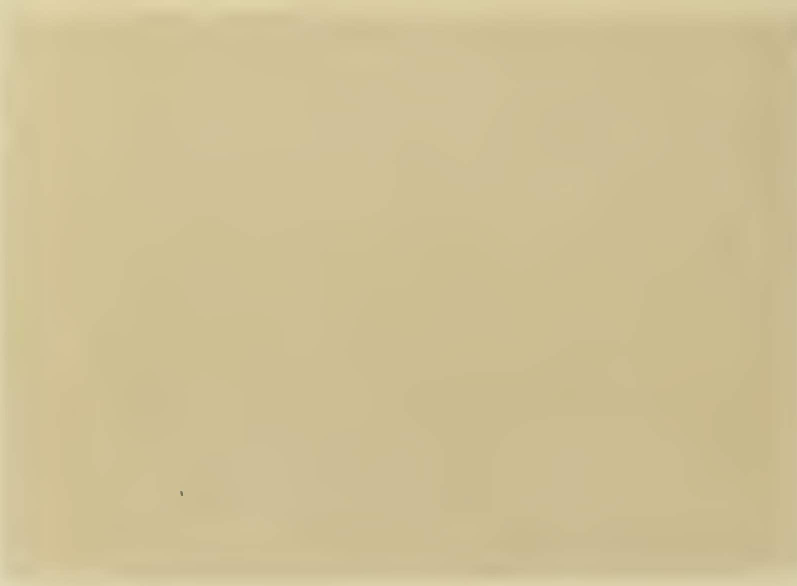


Fig. 6

Photographs of Oscillatory and Unidirectional Sparks

a

b



the approximate frequency and duration of the spark. For more accurate determinations photographs must be made on sensitive plates and observations and measurements made from them.

Several observations were made with this method for various spark lengths and speed of lenses using both air and hydrogen in the corona tube. In the first experiment corona was produced in air at a pressure of 500 mm. by a potential of 14,000 volts. The spark gap was about 1.5 mm. in length and the lenses were driven at a speed of 2,000 r.p.m. A photograph was taken but the individual sparks showed no trace of being oscillatory.

To spread the spark images out the lenses were dirven at a higher speed of 6,000 r.p.m. and the spark gap set at 1.19 mm. This arrangement allowed a passage of about 2,500 sparks per second and a speed of about 100 feet per second across the plate. The photograph Fig. 6b clearly showed that the sparks were not of an oscillatory character but unidirectional, only a sharp line was recorded as each spark passed and their duration was less than 1/100,000 second. Moreover each spark was a little brighter at the negative electrode showing that they all passed in the same direction and were of the same character.

With hydrogen in the tube at a pressure of 744 mm. and a potential of 9,400 volts photographs were taken when the spark gap was 0.75 mm. and 0.3 mm. in length. For the 0.75 mm. gap the frequency of the sparks was about ten per second producing a large number of silvery streamers in the corona tube. When the gap was reduced to 0.3 mm. several hundred sparks passed per second and the corona tube was completely filled with streamers. In every case the sparks were unidirectional, sharp and clean-cut showing no oscillatory character whatever.

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(2) Hot-lime-cathode Braun Tube.

In order to confirm the results obtained by the Boys method and to determine the form of the current curves when a spark is in series a hot-lime-cathode Braun tube was designed and constructed as shown in Fig. 7. The details of the cathode construction are shown in Fig. 8.

A narrow platinum strip P fastened to the insulated brass blocks B_1 B_2 is heated by an auxillary current passing thru the leading-in conductors C_1 C_2. A small spot of CaO placed upon this heated strip has a peculiar property of giving off a stream of slow moving electrons when used as cathode in a discharge tube at a very low pressure. It is necessary to use only a low potential of about 400 volts between anode A and cathode C. The block holding the platinum strip was mounted upon a gimbal support, as shown, in order that the soft cathode beam could be easily adjusted thru a hole in the diaphram D, fall upon the flourescent screen S and there produce a spot of maximum brightness. This double adjustment is necessary for it is impossible to assure by construction the exact direction of the beam.

If a very weak magnetic field is placed at right angles to this beam of slow moving electrons the beam will be deflected shifting the bright spot on the flourescent screen. When the magnetic field is alternating or pulsating the rapidly moving spot will cause a line to be seen on the screen. Now if this line is observed in a mirror which rotates at right angles to it, the line is spread out into a curve which represents the variations in the current of the coil which excites the magnetic field.

The coil used had about 3,000 turns of No.26 enameled copper wire wound in two sections and mounted so that it could be fitted closely to the neck of the tube.

Fig. 7

Photograph of Braun Tube

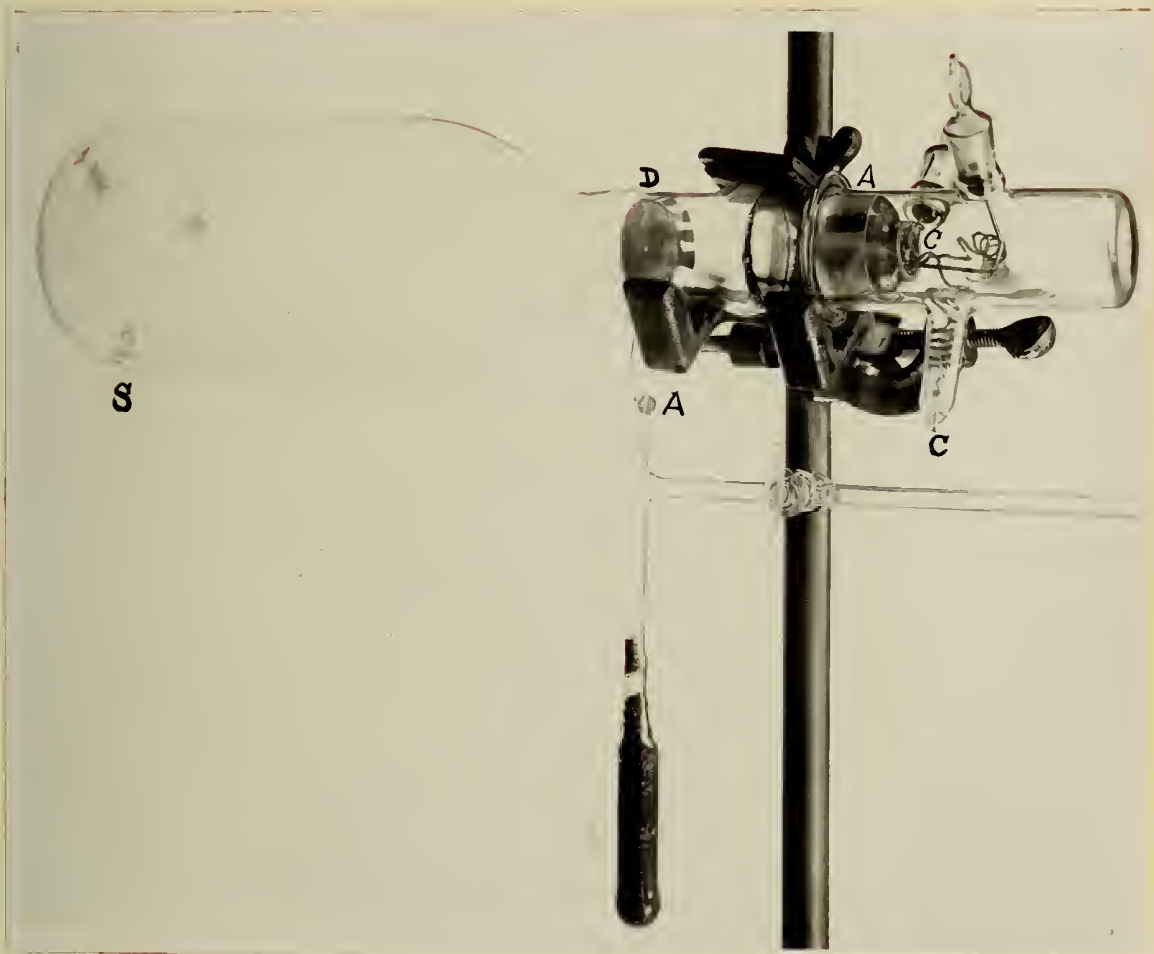
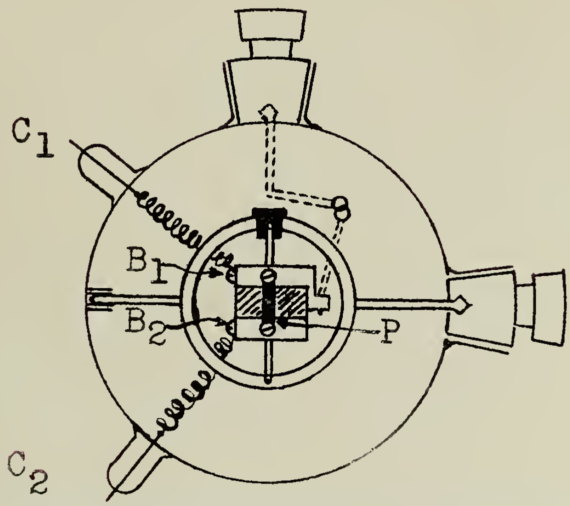


Fig. 8

Detailed Drawing of the-

ADJUSTABLE HOT-LIME CATHODE



Construction and Operation of a Braun Tube.

It might be advantageous to note briefly some of the details necessary in constructing and operating the hot-lime-cathode Braun tube.

1- The cathode should be adjustable in order to get a spot of maximum brightness.

2- A diaphram D is necessary to cut out extraneous light from the hot platinum strip and to stop down the divergent cathode beam.

3- The cathode should be as near the flourescent screen as the sensitiveness of the apparatus permits.

4- CaO mixed with a small quantity of $BaNO_3$ insures a longer life to the lime and may be easily applied as a paste.

5- The anode should be near the cathode, say 1 cm. distant.

6- The potential may be as low as 300 volts and preferably from a constant source as storage cells. The larger the potential the harder the beam becomes.

7- The pressure must be very low and may even be assisted with charcoal and liquid air. Gases are given off from the lime cathode quite freely necessitating constant pumping if the tube is to be used for any length of time.

(3) The Current Curves.

With this hot-lime-cathode apparatus it was easy to observe in the rotating mirror the forms of the current curves when a spark passed and current flowed thru the corona tube. The field coil was connected in series with the circuit, (1) between the spark gap and the corona tube, and (2) between the corona tube and ground or negative terminal of the generators, see Fig. 2. The current forms are sketched in Fig. 9 as they were observed in both of these positions

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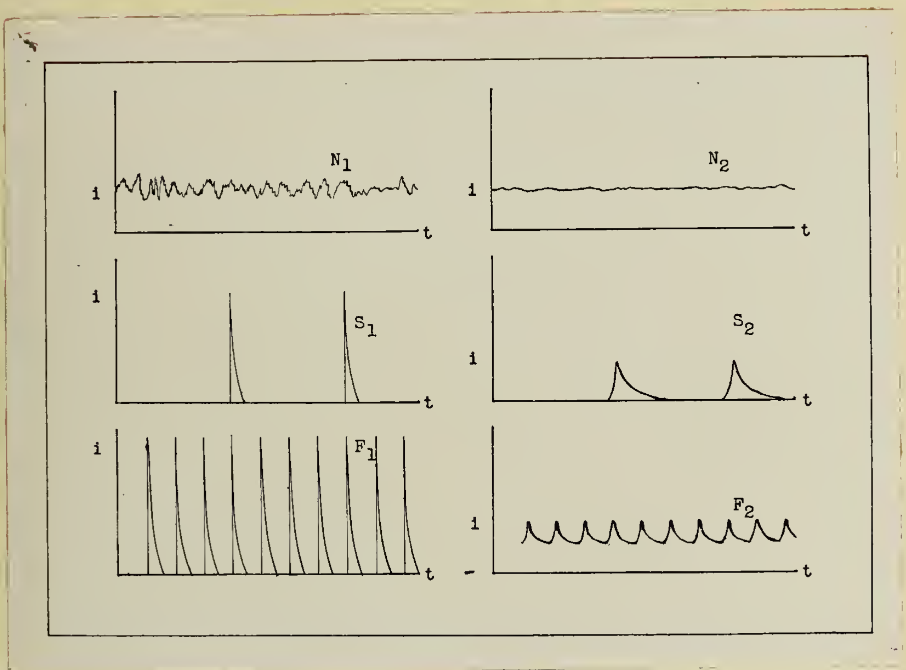
[illegible]

[illegible]

[illegible]

Fig. 9

Currents in the Spark and Corona Tube



and for the conditions, (N) when there was no spark, (S) when sparks were passing slowly and (F) when sparks were passing rapidly.

With the coil in the position (1) and with no spark, the current N_1 was observed to be a small pulsating one having an irregular and ragged edge. These irregularities are quite noticeable and are probably due to poor commutation at the machines as well as fluctuations in their speed of rotation.

With a few sparks passing, say three per second, the current S_1 suddenly jumps to a maximum each time a spark passes and then more gradually falls to zero. The current is always in one direction and its maximum value is larger than N_1.

When the spark gap is adjusted so that sparks pass more rapidly the current F_1 has the same shape as S_1 except that the impulses are crowded closer together.

Connecting the field coil in the position (2) and observing the current thru the tube corresponding to those above we find that for no spark the current N_2 is quite constant giving but a straight line. The irregularities are damped out as the current passes thru the gas of the tube.

With only a few sparks per second we have a peaked current form S_2 rising rapidly and decaying more slowly corresponding to S_1. However it takes a little time for the ionization to take place in the gas and a longer time for the ions to give up their charges or to recombine. Therefore the current S_2 lags a little behind S_1.

For a greater frequency of sparks the ionization comes into play in a more pronounced fashion. The ionization current does not have time to reduce to zero between consecutive impulses from the spark and so the resultant effect is a direct current F_2 with peaks

which correspond to the sparks passing on the other side of the tube. This is ordinarily called a pulsating current.

These current forms are essentially the same when the wire is positive and when it is negative. They show directly that there are no oscillations in either the series spark or the corona tube confirming the results of the other methods and disproving Farwell's hypothesis.

III

CORONA AND THE ARC

1- Electrical Discharges.

Electrical discharges in gases at pressures near that of the atmosphere may be divided into five classes. These are (1) the Dark discharge, where a small current passes thru the gas without making itself visible; (2) the Glow discharge, where a larger current passes and the gas in the immediate neighborhood of the electrodes becomes faintly luminous; (3) the Brush discharge, such as that from points where the glow is irregular and extends into the gas some distance from the electrodes; (4) the Spark discharge, which is a transient phenomenon bridging the whole distance between the electrodes, accompanied by a bright light and a comparatively large current; and (5) the Arc, in which a large current passes between the electrodes in the gas and the ionized vapors of the electrodes producing a continuous light.

Any one of the first forms of discharge may be converted into any one of the later forms by an increase in the potential between the electrodes, depending upon the nature and pressure of the gas, and the spacing, size, capacity and shape of the electrodes.

In our experiments on the corona we have limited the forms of the electrodes to the coaxial cylinders and the parallel wires. The ordinary corona may be classed as a glow discharge, as in the case of the positive wire without a spark, or as a brush discharge as in the case of the negative beads or the positive streamers. This glow or brush discharge under certain conditions goes over into the arc and it is this transformation which we wish to consider in this section.

2- Arc-over upon Opening the Line Switch.

It has been observed time and again that an arc easily forms when the line switch connecting the tube is opened, especially when the wire in the corona tube is positive and a fairly large current is passing in the glow discharge. A small ammount of data has been collected from previous experiments where note was made of this arcing after running up a characteristic current-voltage curve and then opening the line switch.

The curve A Fig.10 shows the current and arc-over potential relation at different pressures for a corroded steel wire 0.041 cm. diameter strung in a cylinder of 3.63 cm. inside diameter. The current recorded is that passing in the corona diacharge just before arcing takes place. It is seen that it is nearly constant for all pressures.

Curve B Fig.10 shows the relation between pressure and arc-over voltage for this constant current. The conclusions which have been drawn from the available data are as follows:--

1- For a given configuration of electrodes the arc-over takes place as soon as the current has reached a certain value which is nearly constant for all pressures.

2- Arc-over occurrs at lower voltages for smaller wires.

3- For a constant current the arc-over voltage for the positive wire is nearly a linear function of the pressure, and may be written-

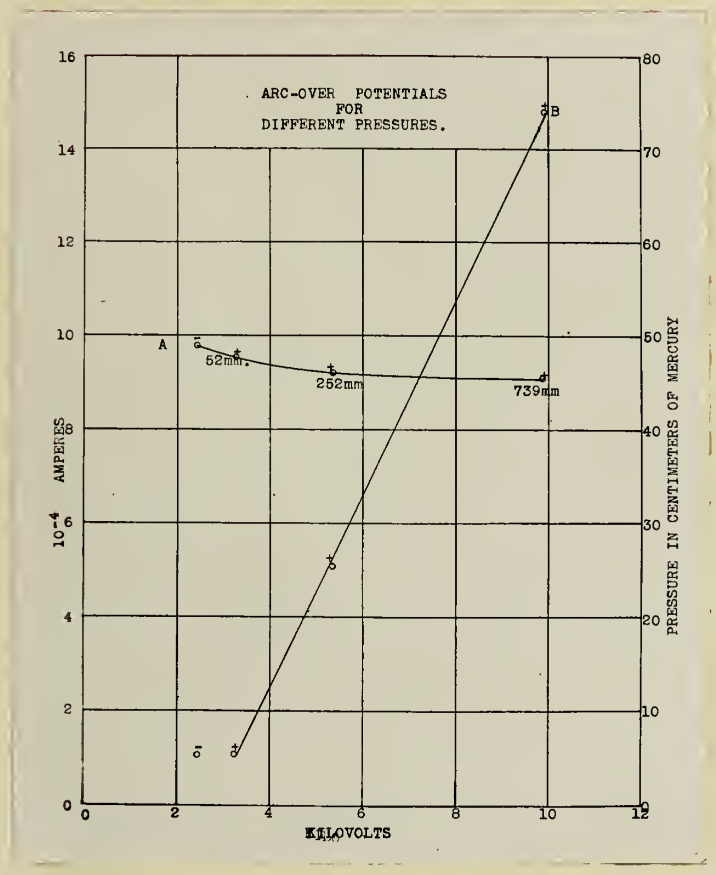
$$V = (aP + b)\ cR$$

where, V = arc-over voltage, P = pressure, R = radius of wire, and a, b, c, are constants.

4- At low pressures arc-over for the negative wire occurrs at a less voltage than for the positive wire.

5- At high pressures (near atmospheric) arc-over for the positive

Fig. 10


ARC-OVER POTENTIALS
FOR
DIFFERENT PRESSURES.
A
B
52mm.
252mm
739mm
10^{-4} AMPERES
PRESSURE IN CENTIMETERS OF MERCURY
KILOVOLTS
0
2
4
6
8
10
12
14
16
10
20
30
40
50
60
70
80

wire takes place at a less voltage than for the negative wire.

3- Cutting out Water Resistance.

The water resistance connected between the generators and the main bus bar was replaced by a 0.5 ampere fuse in order to see if it has any affect on the corona discharge with and without a spark. The visual forms were studied with the coaxial cylinders (the inner one No.20 copper wire) as well as with parallel (No.20 copper) wires as electrodes.

With the cylindrical electrodes the general results obtained showed that the usual characteristic visual forms of the corona discharge were not materially altered either for positive wire or negative wire, with and without a series spark. The only noticeable change was an increased brightness in the positive uniform glow, streamers and negative beads. With the water resistance cut out the available energy was increased about 100 times or in other words to 10 kilowatts. The negative beads and the positive streamers while much brighter were also in a more agitated state moving rapidly back and forth on the wire and would go over into the arcing stage much easier than they would with the water resistance connected. The axial wire was No.20 copper tightly stretched but it was easily set into violent vibration, at 739 mm. pressure and 12,700 volts, within a few seconds after closing the line switch. The applied potential fluctuated at times as much as 100 volts resulting in the more unsteady discharge. The water resistance has the effect of damping out the smaller variations.

The ease with which the arc formed was also noticed in experiments with No.20 wires strung parallel to each other, spaced 1 1/8 inches apart and sealed into a glass tube. At a pressure of 450 mm.

and a potential of 17,000 volts patches of uniform blue glow formed on the positive wire accompanied by beads or fuzzy glow just opposite on the negative wire. The glow on both wires was very bright without the water resistance and an arc would easily form in a few seconds after the clear negative beads appeared or shortly after a spark was placed in series giving rise to the positive streamers. The appearance of the positive and negative discharge with and without the series spark was the same as noted for the cylindrical electrodes.

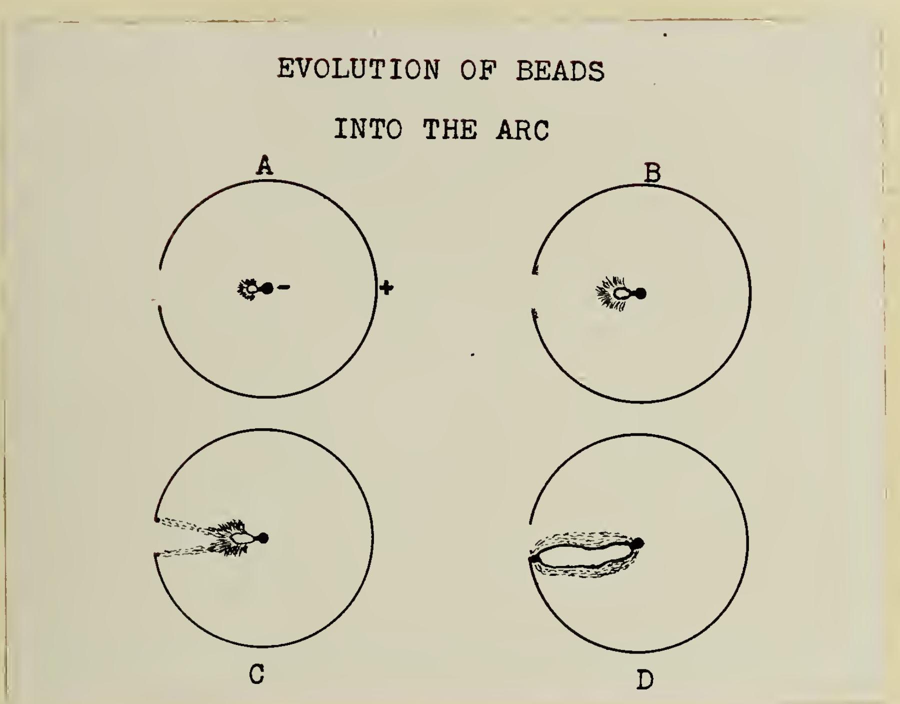
4- Phosphoresence of the Glass Tube.

When an arc was formed on the parallel wires at 50 mm. pressure and 4,000 volts a green phosphoresence was produced in the soda glass of the tube around the position of the arc. This phosphoresence was also seen at pressures down to 3 mm. At 50 mm. the arc does not extend continuously from one wire to the other but presents a broken appearance. From a stationary bright purple spot on the positive wire a pink or purple arm surrounded by a faint greenish glow extends toward the negative wire. This arm or brush shrinks as the pressure is lowered and may entirely disappear. A thin cylinder of moving intense blue glow encases the negative wire and becomes longer and of larger diameter as the pressure decreases.

5- Evolution of Beads into the Arc.

While working with hydrogen it was noticed that when the wire was at a given potential above the critical glow voltage, the current in the beads would increase with the time, the beads would increase in size and in a short time would combine to form an arc. Detailed observations were made on this point. The sketches in Fig. 11 show the evolution of a negative bead in hydrogen into an arc from a No.20 copper axial wire when the pressure was 734.8 mm.,

Fig. 11



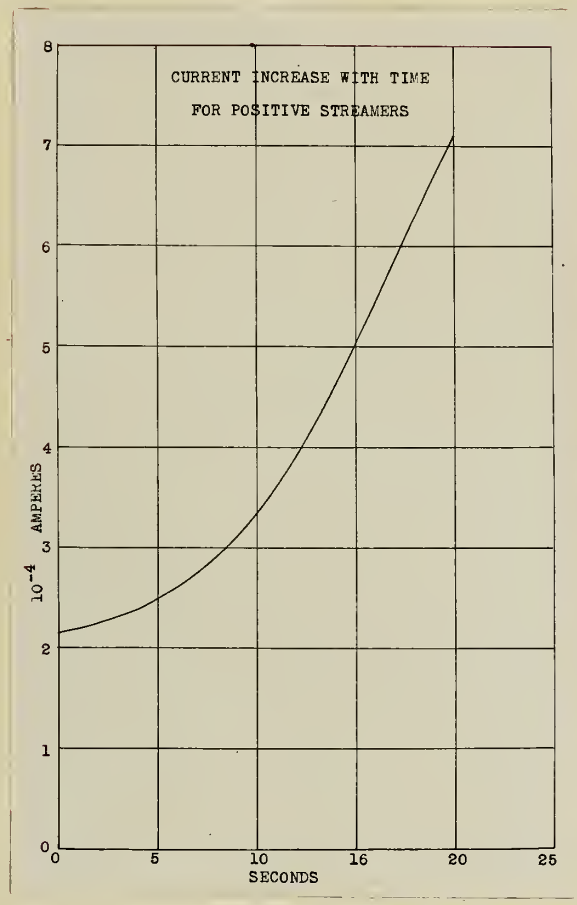
the potential 6,500 volts and no spark in series.

On closing the switch several beads were formed which soon combined into one, much larger and brighter as shown in Fig. 11A. This bead seemed to take hold on the wire at a surface irregularity and remain fixed there. A bright reddish spot on the wire formed the base of the bead while a bright blue-white core extended out from that toward the bright spots on the edge of the observation slot and shaded off into a milky glow or brush. As time proceeded the core grew larger and brighter and the milky glow of the brush reached farther toward the tube, as in B. Soon a faint reddish glow, C, appeared in the gas proceeding from the bright spots on the tube and extending toward the bead. This glow continued to increase in brightness for a short time until the arc D flashed into existence. The arc had a very bright tubular blue-white core surrounded by a hazy reddish glow and extended from a bright reddish spot on the wire to a bright white one on the tube. We may now speak of the negative beads and perhaps the positive streamers as minature or beginning arcs which unite to form a single arc when the current density reaches a certain value.

6- Current increase with Time for the Positive Streamers.

The curve in Fig.12 will serve to show how the current in the streamers increases with the time. At a potential of 11,850 volts, somewhat above that for starting corona glow, in air at 751mm. pressure a spark gap of 0.18 mm. length was placed in series with the tube. Readings of the current were taken at intervals of five seconds and when plotted resulted in the curve as given. An arc passed shortly after 20 seconds but the maximum current before it occurred was not obtained.

Fig. 12


CURRENT INCREASE WITH TIME
FOR POSITIVE STREAMERS
10^{-4} AMPERES
SECONDS
0
1
2
3
4
5
6
7
8
0
5
10
16
20
25

There are several factors which determine the speed of the current increase, the two important ones being the sparking distance and the applied voltage. It will be shown in the following paragraph how the current reaches a maximum value for a certain setting of the electrodes of the series spark gap. It the spark gap is set at this maximum point the current increases at a maximum rate for a given voltage. If the voltage is raised this time between the closing of the switch and the formation of the arc may be reduced to a small fraction of a second.

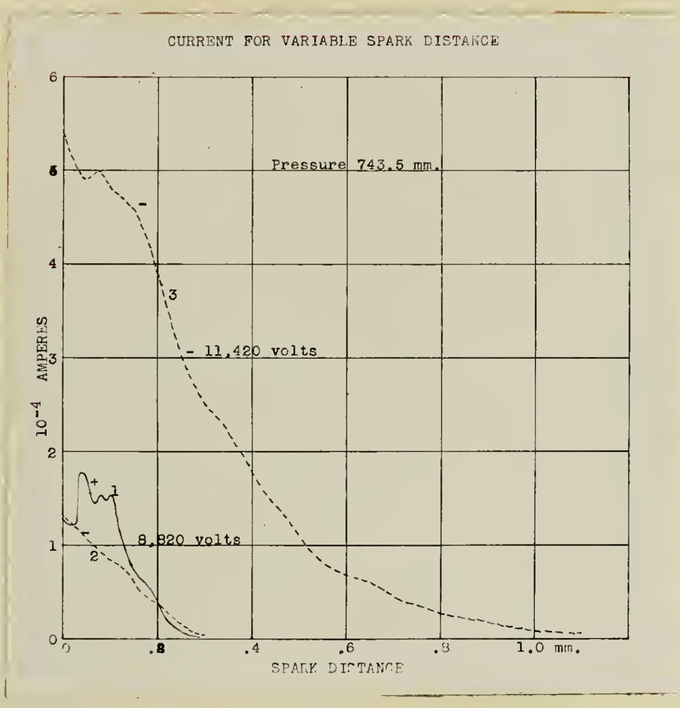
7- Current change for an Increasing Spark Distance.

The curves in Fig.13 show the currents which flow thru the tube for different spark lengths when the voltage and pressure is kept constant. Each reading was taken 10 seconds after closing the line switch in order to eliminate any variations which might arise from accumulative ionization. Curves 1 and 2 are for positive and negative wires respectively at 8,820 volts. Curve 3 is for negative wire at 11,420 volts. The pressure was 743.5 mm. for all curves.

For curve 1 it will be noticed that as the spark gap is opened the current falls to a minimum, quickly rises to a maximum and then gradually falls off to a zero value for a spark length exceeding 0.4mm. The first stage of the curve is accompanied by a dimunition in the brightness of the uniform positive glow but as soon as streamers begin to form the current rises to a maximum value where the streamers are brightest. After this, while the streamers may increase in numbers, they decrease materially in brightness as the spark distance increases. Both of the negative curves 2 and 3 have no maximum but gradually fall off to a zero value as the beads break up and decrease in brightness.

[illegible]

Fig. 13


CURRENT FOR VARIABLE SPARK DISTANCE
Pressure 743.5 mm.
- 11,420 volts
8,820 volts
10⁻⁴ AMPERES
SPARK DISTANCE
0
1
2
3
4
5
6
.2
.4
.6
.8
1.0 mm.

The effect of increasing the voltage may be seen by comparing curves 2 and 3. This means only that a higher point on the characteristic voltage-current curve is taken as a starting point. A positive curve corresponding to 3 could not be obtained since the current at that voltage increases so rapidly that upon opening the spark gap an arc is formed almost immediately.

8- Accumulative Ionization.

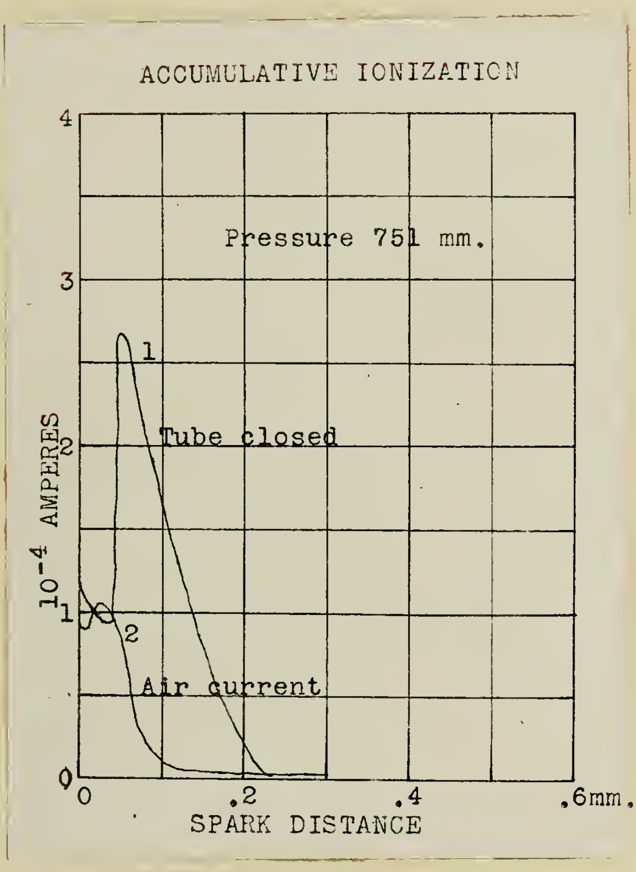
In order to test the relative magnitude of the current due to the accumulation of ions and that due to the spark a current-spark distance curve was taken, when the tube was closed and another when a small current of air was passing thru the tube sweeping out some of the ionized gas.

The curves are given in Fig.14, curve 1 being taken with the tube closed, using a potential of 11,850 volts, and curve 2 with a stream of air passing which necessitated a higher corona voltage of 13,100 volts. Number 2 still has the characteristic maximum in the curve but it is very much reduced in size, whereas number 1 has a very pronounced maximum of a large value. This portrays in a striking manner the effect a short spark has in producing a very great ionization in the gas, and also makes it easy to conceive how the positive arc takes place so readily when the switch remains closed for a little time or is suddenly opened while a large current is passing in the tube.

9- Current-Voltage curves with and without Series Spark.

The ordinary characteristic current-voltage curves as obtained in the process of experiments without a series spark give the negative characteristic as lying above the positive. This relative position is maintained in all cases, with one or two minor exceptions.

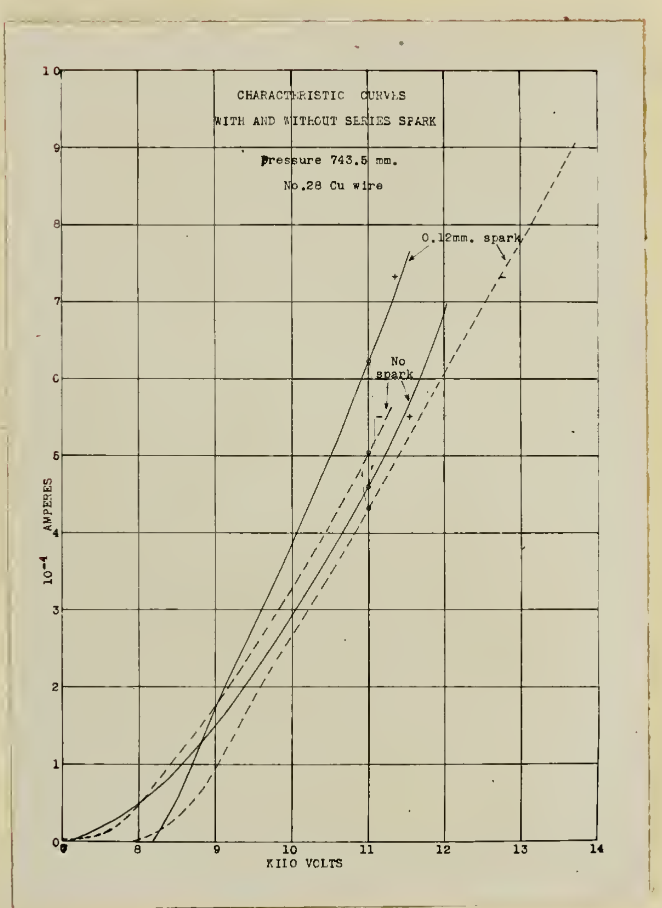
Fig. 14


ACCUMULATIVE IONIZATION
Pressure 751 mm.
1
Tube closed
2
Air current
10-4 AMPERES
0
1
2
3
4
0
.2
.4
.6mm.
SPARK DISTANCE

When a short spark is placed in series with the corona these positions are reversed and the positive curve lies above the negative except at the starting point where the curves cross giving a lower starting potential for the negative wire, see Fig.15. However the starting potential with the spark in series is higher than for the other case. It might be pointed out also that the characteristics taken with a series spark are more widely separated than those taken without, showing a wider variation in the current from the positive and negative wires for a given voltage.

It was found when the spark gap was closed while current was flowing that the current would drop in a short time to a position on the ordinary characteristic curve. For instance, if the wire is positive at 11,000 volts and a 0.12 mm. spark is in series, a current of $6.2 \cdot 10^{-4}$ amperes will flow. Short circuiting the spark gap will cause the current to drop to the value $4.6 \cdot 10^{-4}$ amperes which is a point on the ordinary positive characteristic curve. Similarly by short circuiting the spark gap when the wire is negative the current will increase to a value which lies on the ordinary negative characteristic.

Fig. 15


CHARACTERISTIC CURVES
WITH AND WITHOUT SERIES SPARK
Pressure 743.5 mm.
No.28 Cu wire
0.12mm. spark
No spark
10⁻⁴ AMPERES
KILO VOLTS

IV

MISCELLANEOUS

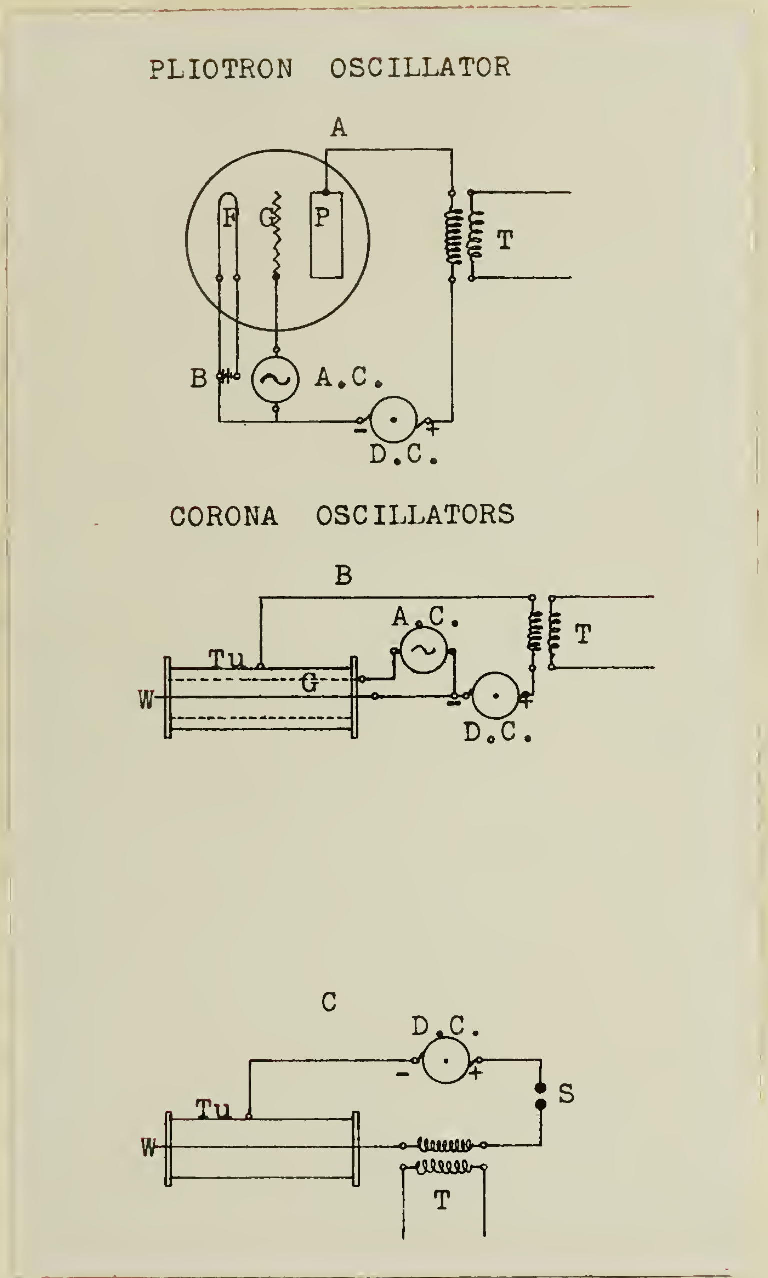
1- Corona Tube as an Oscillator.

In view of the present and previous experiments on the direct-current corona it seems highly probable that a corona tube could be devised for use as a high or low frequency oscillator similar to the 'Pliotron' or the 'Audion' oscillators. In the short time that thought has been given to this several advantages of a corona oscillator over the other types have been formulated. However it still remains for experiment to show that these are improvements and real advantages.

The principle of the Pliotron is shown in Fig. 16A. Three electrodes in the form of a wire, a grid and a plate are mounted in an evacuated glass tube. The wire filament F which can be heated by a battery current B to give off an electronic stream, is connected to a negative direct-current source. The grid or screen G is connected to an alternator for the purpose of setting up an alternating field in the tube, accelerating or retarding the electrons. The plate P which is connected thru the primary of a transformer to the positive terminal of the direct-current source, receives the interrupted stream of electrons.

As this fluctuating current is sent thru the tube and the primary of the transformer T, an oscillatory current is available from the transformer secondary and of a frequency depending on the frequency of the alternator. This oscillator may be made self-exciting by a proper choice and arrangement of resistance, inductance and capacity in the primary circuit. The General Electric Company reports a possible range of frequencies with the Pliotron from 1/2 to 50,000,000

Fig. 16


PLIOTRON OSCILLATOR
A
F
G
P
T
B
A.C.
D.C.
CORONA OSCILLATORS
B
A.C.
T
Tu
G
W
D.C.
C
D.C.
S
Tu
W
T

oscillations per second, with 10 watts of available energy, operating the tube at 600 volts.

Fig. 16B shows in a diagrammatical way a cylindrical corona tube Tu with axial wire W connected for use as an oscillator, similar to the Pliotron. The dotted lines represent the section of a screen cylinder or grid G which is connected to the alternating source.

Experiments have shown that a large corona current may be obtained in hydrogen at a low potential. At 738 mm. pressure a current of $2.5 \cdot 10^{-3}$ amperes is obtained at 2,700 volts from a No.26 copper wire suspended in a cylinder about 4 cm. in diameter and 25 cm. long. At a pressure of 58 mm. a current of $4.3 \cdot 10^{-3}$ amperes may be obtained at a potential of 600 volts. With this current available we may dispense with the hot wire and use only the corona current and the grid arrangement.

Going still farther we may even be able to do away with the grid and the alternating source as well as the hot wire. This may be accomplished by introducing a spark in series with the positive wire or the negative tube and connecting the primary of the transformer on the wire or tube side of the spark gap, see Fig. 16C. The frequency of oscillation in this arrangement may be adjusted simply by changing the length of the series spark.

2- The Telephone as a Corona Detector.

In section I the use of the telephone in connection with the corona and the spark was mentioned. To use the telephone as an indicator of the critical voltage for starting corona without a spark is quite another thing, but it may be used very satisfactorily as a rough detector.

When the potential is gradually increased up to the critical voltage a small current begins to flow at the same time that the first faint glow appears on the wire. This current can be detected with the telephone if it fluctuates a little and can best be heard when the wire is negatively charged.

With a minute spark gap in series the telephone becomes a very sensitive instrument. As soon as the faintest corona glow appears sharp and distinct clicks are heard and easily recognized. This provides a sensitive method for the detection of corona, either direct or alternating, when a sensitive galvanometer is not available or when the glow cannot be observed visually in the dark.

3- Attraction of Parallel Wires.

Farwell has stated that when working with parallel wires he noticed the negatively charged wire bent in toward the positive and the positive wire bent away from the negative. His parallel wires were suspended in a vertical plane and so this effect was probably due to excessive heating and the consequent sagging of the wires under gravitational forces.

In all of our experiments this peculiarity has never been observed. When the wires are small and become heated by the corona they may bend but they always bend down irrespective of their polarity. When suspended in a horizontal plane the wires may sag from heating but whether they sag or not, as soon as the field is applied they always bend in toward each other as one should expect from the fundamental principles of electrostatics.

4- Influence of a Magnetic field on the Corona.

When working with hydrogen at a pressure of 496.5 mm.

[illegible]

[illegible]

[illegible]

[illegible]

and a corona voltage of 6,000 volts on cylindrical electrodes it was found possible to influence the positive streamers by a magnetic field.

A small solenoid electromagnet was suspended over the center of the corona tube. When there was no current thru the magnet the streamers were plentiful, practically filling the tube, but as soon as the field was applied the streamers would slowly fade away and become fewer in number especially in the stronger portion of the field. It took several seconds for this change to take place and for equilibrium to be reached again, but the effect was pronounced and could be repeated. If the magnetic field was now removed the brightness of the streamers would increase again and within a few seconds reach their former value.

Perhaps these streamers are streams of ions and electrons produced by successive collisions with molecules of the gas and moving with a relatively low velocity along lines of the radial electric field. The magnetic field has a component perpendicular to the motion of nearly all of the charges diverting them from their straight paths over longer ones and perhaps preventing them from reaching the wire at all. This magnetic field produced no noticeable effect on either the negative beads or the uniform positive glow.

No noticeable effect could be produced on the discharges when a few turns of wire carrying a heavy direct-current were wrapped around the tube. However the magnetic field in this position easily set the axial wire into violent circular vibration.

5- Figures described by Beads on a Vibrating Wire.

Once when working with air at 749 mm. pressure it was observed that the axial wire (No.28 copper strung in a cylinder 3.6cm.

inside diameter and 25.4 cm. long) when charged to a negative potential of 13,480 volts vibrated in two halves instead of vibrating as a whole as is usually observed. The clear negative beads on the wire indicated the mode of vibration and traced out the paths over which each particular point of the wire moved.

It was very striking to see that one portion of the wire was vibrating in a uniform circular motion while another part was describing a five-pointed star. The wire was allowed to vibrate for some length of time while the different figures were studied. One form of figure would at times slowly change into another and then gradually go over into still a third or a fourth form. The six main types of figures as observed were the circle, flattened ellipse, figure eight, triangle, square, and five-pointed star. These figures are similar to the Lissajous curves obtained with the compound pendulum or with the Braun tube when two superimposed alternating fields at right angles to each other act upon the cathode beam. They may have been set up by an unequal distribution in the field around the wire in addition to having the wire slightly off center.

6- A Demonstration Experiment.

The positive streamers may be demonstrated in a very unique fashion by using a small spherical electrode hanging in the center of a half-silvered glass flask.

A small sphere was suspended in the silvered bulb and insulated by a glass tube, which was also used for exhausting the bulb, and was connected to the positive terminal of the high potential source. The hemispherical silvered surface was connected to the negative terminal thru an electrode which was sealed in the glass. The arrangement first used consisted of a flask of about 10 cm. diameter with a

small central sphere of about 3 mm. diameter. The pressure had to be reduced to about 400 cm. in order to get a good discharge at a continuous potential of 10,000 volts.

With no spark in series only a thin layer of blue glow was seen on the small positive electrode while bright specks appeared on the negative silvered surface. When a short spark was introduced a most remarkable display was seen. Several very bright purple positive streamers appeared issuing from the small central electrode diverging in the shape of funnels toward and almost reaching the spherical silvered surface. The broad ends of these streamers were in constant agitation sweeping back and forth in the gas like majestic plumes.

This experiment may be performed with either direct or alternating current since the positive streamers are produced in both cases by the introduction of a short series spark. If high potential transformers are available larger glass flasks may be used in order to increase the dimensions of the discharge and to bring these streamers out in a more spectacular display.

V

THEORETICAL DISCUSSION

1- Corona Theories.

Nearly all of the theories which have been proposed up to date, by Townsend, Davis and others, to explain the corona discharges have been based on only one assumption, that the gas is ionized by collisions. The writer (Loc. cit.) has previously proposed a theory which adds a second assumption, that there are electrons and perhaps positive ions given off from the metal surfaces of the electrodes. These two assumptions allow an explanation of a wider range of experiments but still this theory seems inadequate to explain all.

Dr. J. Kunz (Phys. Rev. Ser.2 V.8 No.1 p.28 1916) has worked out a theory for the beginning corona in which he incorporates additional assumptions and by which he is able to explain a large portion of the phenomena which occurr in the discharges. His theory is the most rational and comprehensive one which has been proposed up to this time.

We know that ions are produced in the gas by collision with moving electrons or atoms. We also know that ionization may be produced by other means such as light, X-rays and electric fields. In the corona experiments we have very strong electric fields so we may attribute a portion of the ionization to the splitting up of the atoms by the field. In the gas besides the ionization we have recombination and diffusion to deal with. In order to arrive at any complete satisfactory explanation of the corona phenomena it will be necessary to take into account all of these complicated processes. At the present time with our insufficient data it does not seem that we are justified in drawing many conclusions nor in formulating a

general theory of these phenomena. Perhaps the processes involved are much more complicated than we can imagine at the present time, however we may attempt to explain some of the particular forms of the discharge.

2- The Positive Corona Glow.

The uniform corona glow on the positive wire (see Fig.4) is probably best explained by assuming an ionization in the gas near the wire due to the strong electric field. J.S. Townsend in his book entitled "Electricity in Gases", has shown that when air conducts at the positive wire ionization can take place only where X, the field strength, is greater than 30 kilovolts per centimeter. Which means that the ions are generated inside a cylinder of radius C given by the equation, $2\ E/C = 30$, where E is the charge per unit length of the wire. The length of the path over which ionization takes place is, $C - a = X_1 a/30 - a$. X_1 is the critical force at the surface of the wire of radius a. From observations made by Watson on the critical force X_1 necessary to start corona at atmospheric pressure it has been shown that C-a increases from 0.75 mm. to 1.8 mm. for wires whose radii vary from 0.5 mm. to 6.0 mm.

In this region where X is greater than 30 kilovolts per centimeter we will find the positive corona glow which is of a uniform distribution along the whole length of the wire.

As the potential increases the glow becomes brighter and its radius C increases until a potential is reached at which a spark or an arc flashes over.

We may consider the current as being carried by both positive and negative ions which have been generated by the forces in the field. The negative ions near the positive wire are attracted to it and give

up their charges, leaving an accumulation of positive ions which more slowly move outward to the negatively charged tube and are neutralized there. Undoubtedly the processes of recombination and diffusion are going on all the time but the average ionization moving under the action of the electric field is predominant.

3- Positive Corona with a Spark in Series.

When a spark is placed in series with the wire carrying positive corona something in addition to ionization by collision in the gas takes place. The positive streamers appear and the current is greatly increased for certain spark distances. The sudden impulses which come from the spark may cause the field to be impressed so quickly that an extraordinary ionization or tearing apart of the atoms takes place. A rupture is produced in the gas at weak points and the increased ionization takes place over a long radial path which diverges in a cônical shape as the tube is approached. The ions are given greater velocities and hence are able to produce ionization by collisions over much longer paths than can be done when only a steady field is acting.

It is also probable that a disruptive action takes place in the metal at the surface of the wire causing positive ions to be shot off with great velocity. These particles will travel outward under the influence of the radial field and will by successive collisions produce a large number of ions, which in turn may have enough energy to cause further ionization.

These positive streamers are very similar to brush discharges from positive points. J.Zeleny has described some work on point discharges (Phys.Rev. 25 p.305, 1907) where he obtained purple brushes in air from 10 to 15 centimeters long from positive points and

from negative points he obtained much shorter brushes which had a reddish tinge. He also described a disruptive discharge which takes place from the surface of the positive points and which he was able to detect by a telephone as well as by a change in the appearance of the discharge.

Fans or purple streamers similar to those obtained with the spark have been produced without the series spark on rough wires at potentials slightly above the starting point and also from an insulated wire surface at points where the insulation was punctured giving a large field strength at those points, (S.J.C. Loc.cit.). This might enable us to explain the streamers as a superimposed building up and decay of the positive discharge. However the streamers seem to be produced in some manner by the intense and quick acting electromagnetic impulses which travel to the tube from the spark. It would seem that the sudden force exerted on the atom served to tear its charges apart instantaneously, giving rise to high velocity ions and electrons which by multiple collisions with the atoms of the gas produced more ions and electrons.

4- The Negative Corona Discharge.

The glow which first appears on the wire when it is negative is of a uniform character similar to that for the positive wire but of larger radius. This uniform glow may be explained as being produced by ionization by collision in the gas near the wire similar to the case when the wire is positive. When the potential is increased to a voltage somewhat above the critical starting voltage the uniform glow breaks up and the characteristic negative beads begin to appear. At this point we may assume that some sort of a surface tension phenomenon sets in similar to the formation of

moisture on a wire into drops semewhat evenly distributed. Or we may assume that an increasing field strength at points or irregularities on the wire permits electrons to escape from the wire surface and to ionize the gas. These negative brushes are very much like the negative ends of minature arcs which are in stable equilibrium and which unite under certain conditions to form a single arc.

We are justified in assuming an emission of electrons from the negative wire not only from the similarity to the arc and the knowledge that electrons are present in great quantities in all arcs, but the temperature of the beads is high especially at the cores on the surface of the wire and it is observed that the wire surface becomes pitted at these points. A considerable ammount of heat is generated in the tube if the corona is allowed to act for a few minutes.

The negative characteristic current-voltage curves also indicate electron emission since they lie above the positive curves in all cases and rise more rapidly as the potential is increased. They also rise more rapidly as the pressure is decreased and they are influenced by the nature of the metal of the wire as well as its surface condition.

5- Negative Corona with a Spark in Series.

When a spark is placed in series the destruction of the negative beads may be explained as a superimposed building up of the negative discharge from the uniform cylindrical distribution to the concentrated bead form and a decay back thru the period of uniform glow. If the spark gap is short the sparks pass rapidly and the ionization continues almost as well as when there is no spark in the circuit. The current from one passing impulse does not have time to decay very far before the next impulse arrives and builds up the beads again.

For the longer gaps and the less frequent sparks the process of increasing and decreasing ionization has a longer time to act between consecutive impulses and consequently the glow appears more evenly distributed over the whole length of the wire. The stroboscope has shown that the glow takes place only when a spark passes but for a very rapid frequency of sparks the slight lag in the ionization behind the spark really allows the glow to appear continuously.

SUMMARY

1- The characteristic corona glow on positively and negatively charged wires has been described for Air, Hydrogen and Illuminating Gas.

2- Striking changes in the characteristic discharges, which arise from the introduction of a spark in series with the corona tube, are described in detail.

3- These changes in the corona discharges are shown not to be due to oscillations.

4- A hot-lime-cathode Braun tube has been developed and used in observing the weak pulsating currents which pass thru the spark and the corona tube.

5- A correlation between the arc and the corona has been made.

6- Possibilities for using the corona tube as an oscillator have been suggested.

7- Miscellaneous experiments are described.

8- A discussion of the theory and a partial explanation of the corona discharges is given.

In conclusion I wish to thank Dr. J. Kunz for suggesting this work and for his kind interest and help during its progress. I am also indebted to Prof. A. P. Carman who has given suggestive criticism and provided facilities for the investigation.

VITA

Sylvan J. Crooker was born at Fairmont, Minnesota July 3rd, 1893. He received his early training in the public schools of that city graduating from the Fairmont High School in 1910.

He was a student at Carleton College, Northfield, Minnesota from 1910 to 1914, and received the B.S. degree in June 1914.

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He has published in the Physical Review, October 1916, a paper entitled, "Direct Current Corona from Different Surfaces and Metals".